PATENT SPECIFICATION

DRAWINGS ATTACHED

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COMPLETE SPECIFICATION

Improvements in or relating to Optical Systems

We, HARRIES TELEVISION RESEARCH LIMITED, a British Company, of Bank of Bermuda Building, Hamilton, Bermuda, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

In optical systems it is sometimes desirable to employ an "oblique projection system," that is to say, a system in which the optical axis is not normal to the viewing screen where it meets the latter. This need is particularly felt in projection television systems, both for colour and monochrome reproduction. In colour television projection systems employing a number of separate projectors, the optical axes of the three projectors cannot all be normal to the viewing screen; while in monochrome television systems a more compact television receiver may be produced if oblique projection is used because, for example, it is sometimes difficult to accommodate all the components of a television set in the spaces left on each side of a centrally located normally projected system without obstructing the light beam. A need for oblique projection systems also exists with respect to photographic and cinematographic applications. Although often desirable, obliquity of the optical axis has been employed only to a very limited extent since it results in an unsymmetrical distortion of the image on the projection screen in which the part of the image towards which the axis is inclined is compressed both horizontally and vertically and the other part is extended both horizontally and vertically. This distortion (which we shall refer to in this specification as "keystone" distortion) may be accompanied by pincushion or barrel distortion in which the sides of the image become concave or convex. In many applications, such as domestic television receiving systems and cinematographs, there is a special difficulty in that the optical projection system should, if possible, have only a short "throw," that is to say, the optical path between the projector and the viewing screen should be quite short. A small lateral displacement of the projector will then result in a far greater obliquity of the optical axis than would be the case in long-throw systems (such as a cinema projection system in a theatre) and the distortions would, therefore, be far greater. The distortions are particularly undesirable in colour television and colour cinematograph systems which use three projectors, one for each primary colour, since the different colours will not be in exact register away from the centre of the screen. It is believed that these difficulties have resulted, for example, in a reduction of interest in three tube colour television receiving systems, despite certain advantages of these systems, and a concentration of effort on receiving systems employing a single tube, for example, systems in which the colour tube has a tri-colour phosphor dot screen, aperture mask and three electron guns. The present invention (although not confined to oblique projection television systems) has for one of its objects to reduce the distortion in such systems to within acceptable limits.

In the case of optical systems which are not oblique it is theoretically possible to correct barrel or pincushion distortion by suitable combinations of lenses, and, in addition, we have found that very strong distortion of this kind can be corrected by means of a suitably shaped aspheric plate placed at a considerable distance from an aperture stop in the system. It might be supposed by analogy that the asymmetrical keystone distortion found with oblique projection systems could be similarly corrected by, for example, a plate or lens system of suitable shape. We have found, however, that it not possible to correct the key-

stone distortion of oblique projection systems by this means.

We have found that the reason for the failure of lens combinations or aspheric plates, to correct the keystone distortion of oblique projection systems is that there is, in fact, no possible shape of the continuous surface of any lens or aspheric plate which will do this. We may exemplify this by considering a simple case very near the axis of an oblique optical system. Assume that a refracting plate intended to correct keystone distortion is placed on the optical axis with its face perpendicular to that axis. Let us take co-ordinate axes x and y in the plane of the face of the plate, and an axis z perpendicular to x, y. We have found that the components of the slope which the refracting surface should have at any point (x, y) on the surface of the plate to correct keystone distortions will be given by the partial differential equations

$$\frac{\partial z}{\partial x} = Cy^2$$

$$\frac{\partial z}{\partial y} = Cxy$$

where C is a constant. Thus, it might be expected that the form of the refracting surface of the plate would be given by some equation $z = f(x, y)$ which would be a solution of these differential equations with appropriate boundary conditions; but, unfortunately, these differential equations were found to constitute a Pfaffian system and no solution exists in the form $z = f(x, y)$. This means that we have proved that there is no continuous surface of a lens or corrector plate such that the components of the gradient vary in accordance with the above differential equation and this, in turn, leads to an apparent impasse because it means that keystone distortion in oblique projection systems cannot be solved by any known optical element, for example a lens, prism or aspheric plate.

We have also found, however, that to achieve definition of the kind commonly necessary in television receiving systems, the optical projection system need not be of exceptionally high grade and we have utilised this fact to circumvent the impasse.

According to the invention, a distortion correcting device for an oblique optical system has a surface which varies in slope and is composed of a number of facets separated by lines of discontinuity of slope, the gradients of two facets separated by a line of discontinuity of slope being such that no relative change of level of the facets can result in a surface of continuously changing gradient, and the gradients of each facet being such that the paths of a bundle of rays arriving at that facet from the object in the optical system are modified so as to displace the points of arrival of the rays at the image surface into such positions that keystone distortion is substantially avoided. In addition, the slope of each facet may be modified to include additional corrections for other distortions, such as pincushion distortion. The facets must be small enough to provide a reasonable change of gradient over the surface of the device or the distortion will not be sufficiently counteracted, and the facets must not be so small as to produce diffraction effects. We have found that the abrupt steps at the lines of discontinuity between the facets are not objectionable provided that the distortion correcting element is placed at a sufficient distance from the aperture stop of the system and providing that the image is not required to be of much better definition than is commonly found in television systems. The invention is applicable to oblique projection on to screens of any shape.

The facets can be in the form of squares, triangles or hexagons or any two-dimensional design, the design being governed in general by manufacturing convenience. The gradient will, in general, change more rapidly in some parts of the device than in others, and it may, therefore, in many instances be convenient to use smaller facets in the parts where the gradient changes rapidly and to use larger facets elsewhere.

The slope or gradient of each facet, its position and shape, can be calculated by the usual methods of numerical computation used by those skilled in the optical art, guided by the geometry of the optical system and the shape and obliquity of the image surface, which may be a viewing screen. In greater detail, it is first necessary to decide at which point in the system the facetted corrector should be placed. In order that its effect on the distortion should be as great as possible and on the other aberrations as small as possible, it will be understood by optical designers that it should be placed as far as possible from the aperture stop or exit pupil of the projector, up to, say, half-way to the viewing screen. If it is nearer to the screen its effect on distortion also becomes greatly diminished. There will be other considerations, such as the close proximity of other projectors, which set a lower limit to the distance from the screen. Thus a defined position is found.

Next a series of principal rays is calculated and the rays are traced from the optical object to the screen (excluding for the moment the corrector element) at different distances from the axis, and the distortion, including both ordinary barrel or pincushion and keystone, is calculated. This must be done at sufficiently close spacings as will be found by experience to given enough data for computing the facets and rays which must be taken in a number of meridian planes at suitable angles to that

one which is perpendicular to the screen. The method of ray-tracing and calculation of distortion can be any one of a number well-known to optical designers.

Next, for any given ray the point in which it ought to have met the screen if there had been no distortion is found and from this it is possible to calculate the inclination to the normal which the surface of the corrector facet should have where this ray meets it. This is done by assuming an index of refraction for the corrector corresponding to a material of which it is convenient to make it (such as polymethyl methacrylate) and applying Snell's law of refraction, to find the required wedge angle of the corrector facet. The angle can be on either surface of the plate, but in order to reduce astigmatism it is better to have it on the side nearer the viewing screen if there is pincushion distortion to be corrected in addition to keystone, and on the other side if there is barrel distortion.

This wedge angle must then be determined for each facet by interpolating as necessary between the angles found for the principal rays traced. The discontinuity in slope between facets causes a jump in the displacement, at the image plane, of rays which have passed through neighbouring facets, and the number of facets is chosen by arranging that the jump in ray deviation between neighbouring facets corresponds to less than a picture point on the screen, i.e. less than one definition unit. There is then, in practice, no loss of definition. In television systems, the definition unit is determined by the bandwidth.

In the important and most usual case in which an image is projected obliquely on to a plane screen then, in the absence of the correcting device according to the invention, a rectangle in the object plane of the projector system is transformed into a keystone-shaped image as mentioned above and we have noticed that this distortion is such that image points are displaced radially from their correct position. This radical displacement of the image points has led us to a simplification in the design of the correcting device, which can in this instance consist of a number of radial sectors. This simplifies the manufacture of the device, each sector of which is a portion of a different axially symmetric surface, and has a slope which changes over the sector, in the radial direction, in a continuous manner. The sectors are separated by lines of discontinuity of slope. The corrector plate will be symmetrical about a certain diametral axis.

To calculate the form of a corrector plate comprising a number of radial sectors, a set of wedge angles are determined as explained above for the principal rays in any one meridian plane and are regarded in the case of each radial sector as defining a continuous surface. Thus if the polar co-ordinates of the meridian section of this surface are (ρ, φ, z), φ being the azimuthal angle defining the meridian plane, we have

$$\frac{dz}{d\rho} = \tan \theta$$

where θ is the wedge angle determined as before. Thus z is determined as a function of ρ by numerical integration. The number of sectors is determined as above and if, as will generally be the case, there are no sets of wedge angles θ for all the values of φ required, the missing values are found by fitting the available values of θ for a given ρ to a Fourier series in φ by well-known methods and interpolating for the other values of φ from this.

The distortion near the centre of the image was found to be small and, therefore, the central region of the correction plate may be substantially flat and the inner ends of the sectors which make up the central region can in many instances be replaced by a flat disc to simplify the process of manufacture.

In addition to the keystone distortion found in oblique projection systems, pincushion or barrel distortion may occur. Any facetted or segmented correcting device in accordance with the present invention can be appropriately modified by altering the components of slope of its facets, as explained above, to take into account the correction necessary to remove pincushion or barrel distortion.

Although it is expected that the facetted correction plate according to the invention will find its principal application in mirror projection systems, the use of a facetted correction device in lens projection systems may in some cases be desirable.

In some instances oblique optical systems having facetted correction devices in accordance with the present invention may be used in combination with other projection devices which are not oblique and which have their optical axes normal to the viewing screen. According to a subsidiary feature of the invention, barrel or pincushion distortion can be eliminated in these latter non-oblique systems by the use of an aspheric correcting plate placed as far from the stop or centre of projection as possible in order to keep as low as possible any other aberrations introduced by the plate. The design of the distortion corrector is carried out by determining the angle through which the principal ray at each point of the plate must be bent in the manner already described with respect to facetted plates; the slope of the surface is to a first approximation proportional to this angle and a more exact calculation can be made using the well-known law of refraction.

In oblique projection systems which include a facetted distortion corrector in accordance with the present invention, and which are of short focal length and small depth of focus, it

is advantageous to tilt the phosphor screen, transparency or other surface forming the object of the optical system in such a manner that the focusing of the image, from the side nearest to the projector to the side furthest therefrom, is rendered more uniform. In lens projection systems, for example, the screen is tilted about an axis perpendicular to the optical axis of the projector, in such a manner that the angle made by the plane of the screen with the plane of the object is increased.

In order that the invention may be better understood several embodiments will now be described, by way of example, with reference to the accompanying drawings, in which:

Figures 1A and 1B show two facetted distortion correction plates;

Figure 2A shows a further facetted distortion correction plate in which the facets have the form of sectors;

Figure 2B is a sectional view of the plate shown in Figure 2A;

Figure 3 shows diagrammatically a television receiving system employing a single cathode ray tube and associated optical system having its optical axis arranged obliquely with respect to the viewing screen;

Figures 4, 5A, 5B and 5C show constructional details of the cathode ray tube and optical system of Figure 3A;

Figures 6A, 6B and 6C represent diagrammatically a plan view, side elevation and a sectional view of a colour television receiving system;

Figure 7 shows an alternative arrangement of the colour tubes in a colour television receiving system;

Figure 8A represents the aspheric distortion correction plate used with the centre tube of the receiver of Figure 7;

Figure 8B is a sectional view of the plate shown in Figure 8A; and

Figure 9 shows diagrammatically a cinematograph projector for projecting separate colour films on a common viewing screen.

In Figure 1A the facets of the distortion correction plate consist of concentric rings separated by concentric lines *d* of discontinuity of slope. Figure 1B shows facets which run in parallel straight paths across the distortion corrector and are separated by straight lines *d* of discontinuity of slope. These plates can be used in systems for projecting obliquely on to a plane screen, and in such a case, each facet will slope in both senses. Each facet of the plate of Figure 1A will slope radially as well as along its circular path, and each facet of Figure 1B will slope in two mutually perpendicular directions. These correction plates can be injection moulded from polymethyl methacrylate, for example that known as "Perspex" (Registered Trade Mark), made by Imperial Chemical Industries Limited, of England, or that known as "Plexiglas" (Registered Trade Mark) and made by Rohm & Haas, of Philadelphia, United States of America.

Figure 2A shows a correction plate which consists of a number of radial sectors or facets and which is particularly suitable for use when an image is projected obliquely on to a plane screen because, as explained above, each sector slopes only in the radial sense. Figure 2B shows a section through the plate of Figure 2A. This correction plate may, for example, be used in the television reception system which is illustrated diagrammatically in Figure 3, and includes a cathode ray tube the envelope of which is shown at 18. This cathode ray tube includes within its vacuum envelope a convex phosphor screen and a concave mirror which reflects light from the phosphor screen through the transparent face of the tube.

In Figure 3 the electron gun 16 within the envelope 18 produces an electron beam *e* which is scanned by conventional beam-deflection means (not shown) over the convex phosphor screen 20. Assuming the electron beam to be modulated by a video signal, the resulting image on the phosphor screen is projected on to a plane diffusing viewing screen 22, by means of a modified Schmidt optical system comprising an aluminised spherical concave mirror 24 having a central aperture 25 through which the electron beam *e* passes, an optical stop 26, a meniscus 28 and a distortion correction plate 30 of the kind shown in Figure 2. The vacuum tube envelope 18 has a glass window 32. The axis OA of this optical system is inclined to the normal OX to the viewing screen at an angle of obliquity θ which in the optical system under consideration is 6°. The phosphor screen 20 is tilted, with respect to the optical axis, about a diametral axis normal to the plane of the paper in Figure 3, in order to render more uniform the focusing of the image on the viewing screen 22. The radii r1, r2, r3 and r4 of the mirror 24, phosphor screen 20 and the concave and convex surfaces of the meniscus 28, respectively, and the axial distances d_1 to d_6 indicated on Figure 3 may then have the values set out in Table 1.

TABLE 1.

$r_1 = 44.0$ mm.	$d_1 = 24.8$ mm.
$r_2 = 22.0$ mm.	$d_2 = 21.2$ mm.
$r_3 = 16.5$ mm.	$d_3 = 16.5$ mm.
$r_4 = 21.5$ mm.	$d_4 = 5.0$ mm.
	$d_5 = 43.5$ mm.
	$d_6 = 540$ mm.

Other parameters of the system are given below:—

Aluminised spherical mirror 24 is 50 mm. diameter. Meniscus 28 is 40 mm. diameter. Refractive index 1.523.

Aperture 25 in mirror 12.7 × 17 mm. Optical magnification m = 29.

Angle of obliquity of the optical axis to the normal to the screen $= 6.0°$.

Phosphor tilt angle $= 0.21°$.

Size of raster of phosphor $20 = 12.4 \times 16.6$ mm.

Size of image on viewing screen $22 = 360 \times 480$ mm.

The correction plate shown in Figure 2 may consist of an injection moulding of polymethyl methacrylate, and may have a diameter of 88 mm. diameter and thickness on the optical axis of approximately 5 mm. One side of the plate is plane and the other side is optically shaped. The latter side faces towards the viewing screen 22 in Figure 3. Each of the radial sectors or facets, which are separated by radial lines of discontinuity of slope, is a sector of an aspheric axially symmetric surface and therefore has zero slope along the path of an arc centred on the point 0^1. The sectors numbered 1 and 1^1 are identical, as are the sectors numbered 2 and 2^1, 3 and 3^1, etc. Table 2 shows the configuration of each radial sector of a plate designed to correct for axially symmetric distortion of the pincushion kind as well as for keystone distortion, as a function of radial distance r and reduction h of the thickness of the sector below the thickness at the axis of the plate, as shown in Figure 2. The central portion 34 of the distortion corrector, consisting of a circular region of 12 mm. diameter, may have plane surfaces on both sides of the disc. This modification will be found to assist manufacture. The angular subtent of segments 0 and 14 is 60°; the angular subtent of sectors 1, 1^1, 13 and 13^1 is 16°; and the angular subtents of the rest of the sectors is 8°. The angular position of each of the sectors of the correction plate may be specified in terms of the angle φ, for which the 0° and 180° values are shown by the lines 0^1Y and 0^1Z in Figure 2, about which the correction plate is symmetric. This line of symmetry YZ of the correction plate 30 is indicated in Figure 3 and lies in the plane containing the optical axis OA and the normal axis OX, that is, it lies in the plane of the paper.

TABLE 2

Dimensions in Millimeters

Radius r	Reduction in thickness h							
	Sector numbers							
	0	1,1[1]	2,2[1]	3,3[1]	4,4[1]	5,5[1]	6,6[1]	7,7[1]
6	0.012	0.005	0.002	0.000	0.000	0.000	0.000	0.001
8	0.010	0.004	0.001	0.000	0.000	0.001	0.002	0.002
10	0.007	0.002	0.000	0.000	0.000	0.002	0.004	0.006
12	0.004	0.000	0.000	0.001	0.003	0.006	0.009	0.012
14	0.001	0.000	0.001	0.003	0.007	0.012	0.017	0.022
16	0.000	0.001	0.005	0.009	0.015	0.022	0.029	0.037
18	0.000	0.005	0.012	0.019	0.027	0.037	0.048	0.058
20	0.004	0.013	0.024	0.034	0.045	0.059	0.073	0.087
22	0.012	0.026	0.041	0.055	0.070	0.088	0.106	0.124
24	0.025	0.045	0.066	0.083	0.103	0.125	0.148	0.171
26	0.045	0.071	0.098	0.120	0.145	0.172	0.201	0.229
28	0.072	0.105	0.139	0.166	0.197	0.230	0.264	0.299
30	0.108	0.149	0.190	0.223	0.260	0.300	0.341	0.382
32	0.154	0.203	0.252	0.292	0.335	0.382	0.430	0.478
34	0.210	0.268	0.326	0.372	0.422	0.476	0.532	0.588
36	0.277	0.345	0.412	0.465	0.523	0.585	0.648	0.712
38	0.355	0.434	0.511	0.571	0.636	0.707	0.779	0.851
40	0.446	0.536	0.622	0.690	0.764	0.842	0.923	1.004
42	0.549	0.650	0.747	0.822	0.905	0.992	1.082	1.172
44	0.665	0.777	0.884	0.968	1.059	1.155	1.254	1.354

TABLE 2 (Continued)

Dimensions in Millimeters

Radius r	Reduction in thickness h						
	Sector numbers						
	8,8[1]	9,9[1]	10,10[1]	11,11[1]	12,12[1]	13,13[1]	14
6	0.001	0.002	0.002	0.002	0.003	0.003	0.004
8	0.003	0.004	0.005	0.006	0.007	0.008	0.009
10	0.008	0.010	0.011	0.013	0.015	0.017	0.019
12	0.015	0.019	0.022	0.025	0.027	0.030	0.034
14	0.027	0.032	0.037	0.041	0.045	0.051	0.056
16	0.044	0.052	0.059	0.065	0.071	0.079	0.087
18	0.069	0.079	0.088	0.098	0.106	0.116	0.127
20	0.101	0.114	0.127	0.140	0.151	0.165	0.179
22	0.142	0.160	0.177	0.193	0.207	0.225	0.244
24	0.194	0.216	0.238	0.258	0.276	0.299	0.323
26	0.257	0.285	0.311	0.336	0.358	0.387	0.416
28	0.333	0.367	0.399	0.428	0.455	0.489	0.525
30	0.423	0.462	0.500	0.535	0.567	0.608	0.650
32	0.526	0.572	0.616	0.657	0.695	0.742	0.792
34	0.643	0.697	0.748	0.796	0.839	0.894	0.950
36	0.776	0.837	0.895	0.950	0.999	1.061	1.126
38	0.923	0.992	1.058	1.119	1.174	1.245	1.317
40	1.085	1.162	1.236	1.304	1.366	1.444	1.525
42	1.261	1.347	1.428	1.504	1.572	1.659	1.749
44	1.451	1.546	1.636	1.719	1.794	1.889	1.987

This table of dimensions applies only to the correction plate designed for the optical system shown in Figure 3 and having the dimensions set out in Table 1. However, it will be clear to those skilled in the art that the dimensions of correction plates for other oblique optical systems can be calculated along the lines previously indicated.

The mould used to make the distortion correction plates of Figures 1A, 1B and 2 by injection moulding may be made of steel with highly polished surfaces protected by chrome plating. It may be made in sections, one for each facet. Thus, referring, for example, to Figure 2, the mould may be constructed out of radial sectors each cut from an axially asymmetric cavity and joined together, with a plane disc 34 in the centre.

Figures 4, 5A, 5B and 5C show details of a suitable form of construction for a part of the optical system shown in Figure 3. The spherical mirror 24 and the phosphor screen

20 are mounted within a metal cylinder 35 arranged coaxially within the envelope 37 of the cathode ray tube 18. The phosphor screen 20 is connected to the metal cylinder by means of a metal ring 36 (Figure 5B) and spider arms 38, which are made as thin as possible in order to obstruct as little as possible of the light from the mirror 24. The metal cylinder 35 has an outer annular ring 39 which abuts against the transparent window 32 of the tube and is connected to this window by a central pin 42, to which the annular ring 39 is connected by spider arms 40. The spider arms 40 are located immediately behind the spider arms 38. Electrical connection is made to the metal cylinder by means of a conductor 44. The optical stop 26 forms part of an insulating casing 46 which is cemented to the moulded glass window 32 and which houses the meniscus 28 and the correction plate 30. The phosphor screen is tilted with respect to the optical axis through an angle equal to the angle of obliquity of the optical axis with respect to the normal to the viewing screen (see Figure 3) divided by the magnification. This angle is exaggerated in Figure 4 for the sake of clarity.

Figures 6A, 6B and 6C show diagrammatically a plan view, side elevation and a sectional view, respectively, of a colour television receiving system which uses the optical system and vacuum tube shown in Figures 2, 3 and 4 and having the dimensions set out in Tables 1 and 2. Four colour tubes are used, a tube 18G having a green phosphor screen, a tube 18B having a blue phosphor screen, and two similar tubes 18R each having a red phosphor screen. The two tubes 18R are used in parallel so that their light outputs are added at the viewing screen, in order to counteract the relatively low luminance efficiency of red colour phosphors. Each tube and its optical system, including the correction plate, lies along an optical axis such as OA (Figure 6A). Regarded in the planes OC, OD, OE and OF in Figure 6C, each optical axis subtends an obliquity angle of 6° to a normal to the viewing screen in these planes. Regarded in plan view and side elevation the components of this angle of obliquity are 4.6° and 3.9° as shown in Figures 6A and 6B. In order to minimise the angle of obliquity the distortion correctors and their holders have been cut away on their adjacent edges as shown at 46 and 48 in Figures 6A and 6B. In Figure 6C the block 50 represents a colour television receiver with an antenna 52 and ground 54. The block 56 represents the usual synchronised scanning generators which supply the line and frame scanning potentials or currents to the deflection coils or plates (not shown) of the tubes by means of links 58. The red, blue and green video signals are applied by means of circuits represented by the blocks 60G, 60B and 60R to the modulator electrodes (not shown) in the tubes 18G, 18B and the two tubes 18R. It is expected that such a television projection system will usually have a short length from projector to screen, so that the depth of focus will also be short. The phosphor screens in each tube are, therefore, tilted through a small angle as described above and as shown diagrammatically in Figures 3 and 4 to minimise the defocussing at the sides of the image.

Figure 7 shows another colour television system having three cathode ray tubes 18G, 18B and 18R having green, blue and red phosphor screens respectively, and provided with corresponding optical projection systems. The blocks 50, 56 60G, 60B and 60R have the same purpose as in the case of Figure 6. Radial distortion correction plates of the general kind shown in Figure 2 may be used in tubes 18R and 18B, although owing to the different angle of obliquity the dimensions of the plates would be different from those given in Table 2. The centre tube 18G is not obliquely arranged with respect to the viewing screen, and therefore, no keystone distortion will appear in the case of tube 18G and its associated optical system. Pincushion or barrel distortion may, however, occur. According to a subsidiary feature of the invention this distortion is substantially corrected by introducing into the optical path of tube 18G a suitably shaped aspheric plate having a surface the slope of which changes in a continuous manner. This is the plate 62 in Figure 7 and is at the same position along the optical axis of tube 18G as the facetted distortion correction plates 30R and 30B along the optical axes of tubes 18R and 18B.

A suitable aspheric distortion correction plate 62 (which may be injection moulded from polymethyl methacrylate) is shown diagrammatically in Figures 8A and 8B. The design of this distortion corrector is carried out by determining, in a manner which will be obvious to those skilled in the art, the angles through which the bundles of rays at each point of the plate must be bent to eliminate pincushion or barrel distortion. It is found that if a facetted distortion correction plate of the general type of that shown in Figure 2 is used with the tubes 18R and 18B of Figure 7, then the gradients over any radius of the optical surface of the aspheric distortion correction plate 62 used with tube 18G will be the same as the gradients over any radius of the sectors 7 and 7^1 of the facetted distortion correction plate; that is, the surface of the plate 62 will be the same shape along all radii as the surface of the two facets 7, 7^1 of the facetted correction plate which lies perpendicular to the axis of symmetry YZ in Figure 2.

The vacuum tube 18G having a green phosphor screen is chosen to occupy the central position in Figure 7, in which the optical axis

is normal to the viewing screen 22, because it is known that the red and blue component images of a colour picture are less critical as regards definition and focus than the green component image, and in the event that the facetted distortion correction plates used in the red and blue optical systems of Figure 7 cause an accidental reduction of definition, as compared with the definition of the green optical system which has a distortion corrector with no facets, it follows that the effect of the loss of definition will be minimised.

As already described in connection with Figures 3 and 4, by combining the use of the facetted correction plate with the tilting of the phosphor screen in an obliquely arranged projection unit of a television receiving system (or each of the obliquely-arranged projection units), any distortion and defocussing at the sides of the image can be reduced. In the case of a multiple tube projection colour television receiving system, by combining these features in each of the obliquely arranged projection units the accuracy of registration of the three images on the viewing screen can be improved. However, it may not in all cases be necessary to provide for the tilting of the phosphors in all of the projection systems used in Figures 6 and 7, because it has been found that a considerable improvement in the appearance of the projected image is obtained in certain cases when only the green image is brought into sharp focus, the improvement provided by the tilt of the additional blue and red images being less noticeable.

A monochrome (black and white) television receiving system employing oblique projection can also be provided, according to the invention, with the facetted correcting device (preferably acromatic) arranged in the path of the light rays in the manner shown in Figure 3. If desired, the system may include a plane mirror arranged to that the light rays are deflected through, for example, a right angle, in order to reduce the physical length of the system.

Figure 9 shows an application of the invention to a cinematograph projector. The three projectors, 64R, 64G and 64B respectively produce red, green and blue colour pictures from colour films fed through each projector in the usual way and synchronised by means of the links 66 and 68.

Due to the reversability of optical systems the arrangements in Figures 6 and 7 can equally well be used for the transmission of television images as for their reception. In this case camera tubes with photosensitive surfaces and appropriate colour filters may be substituted for the discharge tubes 18R, 18G and 18B shown in these figures, the photosensitive surfaces replacing the phosphors used in these discharge tubes. The blocks 50 then represent a transmitting apparatus and the blocks 60R, 60B and 60G represent camera amplifiers.

In the same way the reversability of optical systems enables the arrangement of Figure 9 to operate as a camera device. The element 22 in Figure 9 then represents an illuminated colour transparency which is to be photographed, or a scene which is to be photographed in colour. The cinematograph cameras are represented by 64R, 64G and 64B and are arranged to photograph on films 70, through red, blue and green coloured filters, the red, blue and green component colours of the coloured scene.

Although the correction device which has been described takes the form of a light-transmitting plate, it would be possible to construct a distortion correcting mirror having a facetted surface, the gradients of each facet being such that keystone distortion was eliminated in an oblique projection system.

WHAT WE CLAIM IS:—

1. An optical device for correcting distortion in an oblique optical system, the device having a surface which varies in slope and which comprises a plurality of facets separated by lines of discontinuity of slope, the gradients of two facets separated by a line of discontinuity of slope being such that no relative change of level of the facets can result in a surface of continuously changing gradient, and the gradients of each facet being chosen with regard to the bundle of rays which reach that facet from the object in the optical system so as to displace the points of arrival of the rays at the image surface of the optical system into such positions that keystone distortion in the image is substantially avoided.

2. An optical device for correcting distortion in an oblique optical system, the device consisting of a light-transmitting plate having at least one surface which varies in slope and which comprises a plurality of facets separated by lines of discontinuity of slope, the gradients of two facets separated by a line of discontinuity of slope being such that no relative change of level of the facets can result in a surface of continuously changing gradient, and the gradients of each facet being such that the paths of a bundle of rays from the object in the optical system which pass through that facet are modified so as to displace the points of arrival of the rays at the image surface of the optical system into such positions that keystone distortion in the image is substantially avoided.

3. A device according to Claim 1 or 2, in which the gradients of each facet are such that the bundle of rays passing through the facet from the object in the optical system are modified so as to displace the points of arrival of the rays at the image surface of the optical system into such positions that axially symmetric distortions are also substantially avoided.

4. A device according to Claim 1, 2 or 3,

in which the facets of the correcting device are in the form of radially extending sectors, each sector being a sector of an axially symmetrical surface the slope of which varies in the radial direction only.

5. A device according to Claim 4, in which the central portion of the said surface, from which the sector-shaped facets radiate, is formed as a plane facet normal to the axis of the device.

6. A device according to any one of the preceding claims, in which the facets vary in size, being smaller where the change of gradient is greatest.

7. A device according to Claims 4 and 6, wherein the angular subtents of the sector-shaped facets vary in magnitude.

8. An oblique optical projection system employing a distortion-correcting device according to any one of the preceding claims.

9. An oblique optical projection system according to Claim 8, and in which the optical object is tilted about an axis perpendicular to the optical axis of the projection system to render more uniform the focusing of the image.

10. An oblique optical projection system according to Claim 9, in which the optical elements constitute a Schmidt projection system.

11. A television receiver employing an oblique optical projection system, comprising a distortion-correction device according to Claim 2 or 3.

12. A television receiver employing an oblique optical projection system and including a distortion-correction device according to Claim 4 or 5.

13. A television receiver according to Claim 11 or 12, employing a form of Schmidt optical projection system in which the phosphor screen of a cathode ray tube constitutes the optical object.

14. A television receiver according to Claim 11, 12 or 13, in which the phosphor screen is tilted about an axis perpendicular to the optical axis of the projection system to render more uniform the focusing of the image.

15. An optical system in which images projected by an oblique projection system and a projection system having its axis normal to the image surface are superimposed at the image surface, the oblique projection system including a facetted correction device according to Claim 3 and the normal projection system including a correction device having an aspheric surface the gradients of which change in a continuous manner and are such that the points of arrival of the rays at the image surface of the system are displaced into positions such that axially symmetric distortions are substantially avoided.

16. An optical system according to Claim 15, in which the gradients of the aspheric surface along any radius from the axis of the device are the same.

17. A colour television receiving system employing a plurality of cathode ray tubes having phosphor screens which fluoresce in different primary colours; each tube being associated with an oblique optical projection system and each optical projection system including a distortion-correction device according to any one of Claims 2 to 7.

18. A colour television receiver according to Claim 17 additionally provided with a cathode ray tube associated with an optical projection system having its axis normal to the viewing screen; the normal optical projection system including an aspheric correction device the gradients of which change in a continuous manner and are such that the points of arrival of the rays at the image surface of the system are displaced into positions such that axially symmetric distortions are substantially avoided, and the oblique projection systems each including a distortion correction device according to Claim 3.

19. A colour television receiver according to Claim 17 or 18, in which the phosphor screens of the cathode ray tubes associated with the oblique optical projection systems are tilted about axes perpendicular to the optical axis of their respective projection systems.

20. A colour television receiver according to Claim 17, in which only the phosphor screen of the cathode ray tube which projects the colour requiring the highest definition is tilted about the axis perpendicular to the optical axis of its projection system to render more uniform the focusing of the corresponding image.

21. A colour television receiver according to Claim 18, in which the cathode ray tube which projects the colour requiring the highest definition at the image surface is associated with the optical system the axis of which is normal to the image surface.

22. A colour television receiver according to any of Claims 17 to 21, in which at least two of the oblique projection systems are associated with cathode ray tubes adapted to produce images of the same colour, this being the colour of the phosphor having the lowest luminance efficiency.

23. A television transmitting or photographic camera system using at least one oblique optical system having a distortion-correction device according to any one of Claims 1 to 7.

24. A television transmitting or photographic camera system according to Claim 23, in which the photosensitive surface or film is tilted about an axis perpendicular to the axis of the optical system to render more uniform the focusing of the image.

25. An optical device for correcting distortion in an oblique optical system substantially as herein described with reference to Figure

1A, or Figure 1B, or Figures 2A and 2B of the accompanying drawings.

26. An oblique optical projection system substantially as herein described with reference to Figures 3, 4, 5A, 5B and 5C of the accompanying drawings.

27. A colour television receiver substantially as herein described with reference to Figures 6A, 6B and 6C, or substantially as herein described with reference to Figure 7, of the accompanying drawings.

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PROVISIONAL SPECIFICATION

Improvements in or relating to Optical Systems

We, HARRIES TELEVISION RESEARCH LIMITED, a British Company, of Bank of Bermuda Building, Hamilton, Bermuda, do hereby declare this invention to be described in the following statement:—

In optical projection, it is sometimes desirable to employ an "oblique projection system," that is to say, a system in which the optical axis of the system meets the screen at an angle other than a right angle. This need is particularly felt in projection television systems, both for colour and monochrome reproduction. In colour television projection systems employing a number of separate projectors the optical axes of the three projectors are not in general all normal to the plane of the screen, while in monochrome television systems, it is frequently difficult to accommodate all the components of the television set in the spaces left on each side of a centrally located projection system in such a manner that they will not obstruct the light beams. Such obliquity of the optical axis has been employed only to a very limited extent since it results in a unsymmetrical distortion of the image of the projection screen in which the part of the image towards which the axis is inclined is compressed both horizontally and vertically and the other part is extended both horizontally and vertically. This distortion, which will be referred to in this specification as "keystone" distortion may be accompanied by pin-cushion or barrel distortion, in which the sides of the image become concave or convex. In domestic television receiving systems, there is the further difficulty that the optical projection system should if possible have only a short "throw," that is to say the optical path between the projector and the viewing screen is quite short. A small lateral displacement of the projector would therefore result in a far greater obliquity of the optical axis than would be the case in a long-throw system such as a cinema projection system, and the distortions would therefore also be far greater. The distortions are particularly undesirable in colour television systems using three projectors since the different colours will not be in exact register away from the centre of the screen. It is believed that these difficulties have resulted in a reduction of interest in three-tube colour television systems and a concentration of effort on systems employing a single tube, for example systems in which the tube has a tri-colour phospher dot screen, an aperture mask and three electron guns. The present invention, although not confined to oblique projection television systems, has for one of its objects to reduce the distortion in such systems to within acceptable limits.

It is in principle possible to correct barrel or pincushion distortion either by suitable combinations of lenses, and we have found that very strong distortion can be corrected by means of a suitably shaped aspheric plate placed at a considerable distance from the aperture stop. The aspheric plate will in this case be axially symmetric. It might be supposed that the asymmetrical keystone distortion could be similarly corrected by an aspheric plate of suitable shape, but not axially symmetric. We have found, however, that it is not possible to correct the keystone distortion by means of an aspheric plate of suitable form, as it appears that there is no continuous surface which will do this.

We may exemplify this by considering a simple case very near the axis of the system which is oblique to a plane screen. Assume that a corrector plate is placed perpendicular to the optical axis of the projector and take coordinate axes x and y in the plate, y being in the plane perpendicular to the screen and containing the optical axis, and x being perpendicular to y. Then the components of slope of the surface at (x, y) will be given by

$$\left.\begin{aligned} \frac{\partial z}{\partial x} &= Cy^2 \\ \frac{\partial z}{\partial y} &= Cxy \end{aligned}\right\} \qquad (1)$$

where C is a constant. Thus the form of the surface would be given by the equation $z=f(x, y)$ which is a solution of these differential equations with appropriate boundary conditions; but these equations constitute a Pfaffian system of differential equations, and considered as a purely mathematical problem, there is no solution in the form $z=f(x, y)$. This means that there is no continuous surface such that the components of the gradient vary

according to (1), and this leads to an apparent impasse because the problem cannot be solved by any known optical element such as a lens, prisms or aspheric plate.

We have also found that to achieve definition of the kind commonly found in television receiving systems, the optical projection system need not be of an exceptionally high grade and we have utilized this fact to circumvent the impasse.

According to the invention, there is arranged in an oblique optical projection system a distortion-correcting device at least one of the surfaces of which varies in slope in a discontinuous manner and is composed of a number of facets separated by lines of discontinuity, the components of slope of each facet being governed at least in part, by the equations given above. It will be understood that the values of the components of slope of each facet which would be predicted from the above equations may be modified to include corrections for other aberrations, such as pin-cushion distortion. The abrupt steps between facets are not objectionable provided the element is placed at a considerable distance from the aperture stop and provided the image is not required to be of much better definition than is commonly found in television systems. The facets must be small enough to provide a reasonable rate of change of gradient over the surface of the device according to the equations (1) to avoid undue image distortion, and they must not be so small as to produce diffraction effects.

The facets can be in the form of squares, triangles or hexagons or any two-dimensional repeated design. The gradient will in general change more rapidly in some parts of the plate than in others, and it may therefore be convenient to have smaller facets in the parts where the gradient changes rapidly and larger facets elsewhere. This principle is applicable to oblique projection on to screens of any shape.

In the special case in which an image is projected obliquely on to a plane screen, in the absence of the correcting device according to the invention, a rectangle in the object plane of the projector is transformed into a keystone-shaped image and the distortion is such that any image point is displaced radially from its correct position. This permits a simplification in the design of the correction device, which can in this instance consist of a number of radial sectors. This simplifies the manufacture of the device, since each sector is a portion of a different axially symmetric surface, the slope of which changes in a continuous manner. These surfaces can be separately produced by known techniques, and then the required sectors can be cut from them and pieced together. The finished correction plate will be symmetrical about a given diametral axis. Again it may be convenient to vary the angular substences of the sectors according to the rate of change of gradient. The distortion near the centre of the image is small and therefore the central region of the correction plate is substantially flat and the inner ends of the sectors which make up the central region can be replaced by a flat disc; this simplifies the manufacture.

The distortion-correction device can be made with the necessary accuracy at a reasonable price which will enable the device to be used in a domestic television reception system. Thus we are able to provide a correcting element for oblique projection television systems which substantially corrects the keystone distortion while still enabling a standard of definition which is more than adequate for television receivers. It is also suitable for other oblique projection systems where high-grade definition is not required.

Pin-cushion or barrel distortion may occur both in oblique projection systems and in projection systems in which the optical axis is normal to the screen, the distortion being symmetrical in the latter case. Symmetrical distortion of this kind can be corrected by suitable combinations of lenses, but this is difficult or impracticable when the distortion is very great, as in a concentric system with large field angles, where there is necessarily substantial field curvature. According to a subsidiary feature of the invention, this distortion can be substantially corrected by introducing into the optical path a suitable shaped aspheric plate, placed as far from the stop or centre of projection as possible in order to keep as low as possible any other aberrations introduced by the plate. The design of the distortion corrector is carried out by determining the angles through which the principal ray at each point of the plate must be bent; the slope of the surface is to a first approximation proportional to this angle and a more exact calculation can be made using the well-known law of refraction. Such an aspheric correction plate is useful in colour television systems employing three projectors, one of which has its optical axis normal to the screen. The aspheric plate is placed in the optical path of the latter projector to correct symmetrical distortion in the corresponding image.

In the case of an oblique projection system, the facetted correcting device which has been described is modified by altering the components of slope of its facets to take into account the correction necessary to remove pin-cushion distortion.

Although it is expected that the invention will find its principal application in mirror projection systems, the use of the facetted correction device in lens projection systems may in some cases be desirable.

In projection systems of short focal length and small depth of focus, it is advantageous to tilt the transparency, phosphor screen or other

surface forming the object in such a manner that the focusing of the image, from the side nearest to the projector to the side furthest therefrom, is rendered more uniform. In lens projection systems, for example, the screen is tilted about an axis perpendicular to the optical axis of the projector, in such a manner that the angle made by the plane of the screen with the plane of the object is increased. An example of a mirror projection system employing tilting of the object will now be described.

A television projection system employs a cathode ray tube in which a modulated scanning electron beam passes through a central hole in a concave spherical mirror before striking a part-spherical screen consisting of a phosphor layer on an aluminium plate of rectangular periphery and of smaller dimensions than the concave mirror. Light from the phosphor screen strikes the reflecting surface of the concave mirror and is reflected back past the phosphor screen (at the sides of the latter) and through a window in the vacuum envelope. It then passes through a stop plate and, if necessary, a meniscus correcting lens before forming an optical image on the final viewing screen. This projection system has the advantage that light from the front face of the phosphor screen (i.e. the side struck by the electron beam) travels directly to the concave mirror from which it is reflected onto the final screen; in conventional direct-viewing cathode ray tubes, on the other hand, the rear face of the phosphor screen is viewed through at least one thick layer of glass. A further advantage is that there is less discolouration by X-rays of the glass forming the front of the vacuum envelope, since the phosphor screen points away from the glass front.

According to the invention, in an oblique projection system of this kind a facetted correction plate is interposed between the meniscus correcting lens and the final viewing screen. This removes the keystone distortion and has the advantage that it involves no additional loss of light from the mirror.

Furthermore, it is expected that such a television projection system will usually be of short length, from projector to screen, so that the depth of focus will also be short, and the phosphor screen is therefore tilted through a small angle as described above to minimise the defocusing at the sides of the image.

By combining the use of the facetted correction device with the tilting of the phosphor screen in each of the projection units of a colour television system (or each of the obliquely - arranged projection units), the distortion and defocusing at the sides of each individual image can be reduced and the accuracy of registration of the three images on the screen can be improved. However, it may not in all cases be necessary to provide for the tilting of the phosphors in each of the projection systems, as it has been found that a considerable improvement in the appearance of the projected image is obtained when only one of the images is brought into sharp focus, the improvement provided by the focusing of the additional images being less noticeable. We have found this to be particularly so when the colour projector with the least depth of focus is arranged perpendicularly to the screen. With this arrangement we take advantage of the different allowable depths of focus of the images of different colours to the optimum appearance of the image with the minimum of difficulty in the manufacture of the tubes.

A monochrome (black-and-white) television system employing oblique projection can also be provided, according to the invention, with the facetted correcting device (preferably achromatic) arranged in the path of the light rays, and defocusing at the sides of the image when the field of focus is short can be substantially overcome by tilting the object surface, which, in the case of a mirror projection system of the kind described above, is the curved phosphor screen. If desired, the system includes a plane mirror arranged so that the light rays, after passing through the correcting prism, are deflected, for example through a right angle, in order to reduce the physical length of the system. In a similar manner in a colour television system four projection tubes can be arranged one above the other and the emergent light rays deflected by one or more plane mirrors to strike a suitable screen obliquely. If each projection tube is already provided with its own distortion - correction device, the individual correcting plates can be modified to take into account the obliquity common to all the tubes in addition to their individual obliquities caused by the need for superimposition of the individual images.

The invention is also applicable to television transmission or photographic systems in which the camera is arranged obliquely with respect to a scene to be transmitted or photographed. In the case of a television transmission system, an optical system similar to that described above for a projector tube can be used to project an image of a scene on to a photosensitive mosaic in an electron discharge tube.

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897361 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

Fig. 1A.

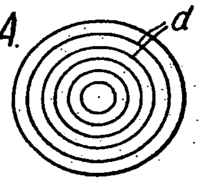


Fig. 1B.

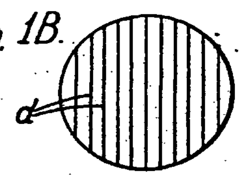


Fig. 2A.

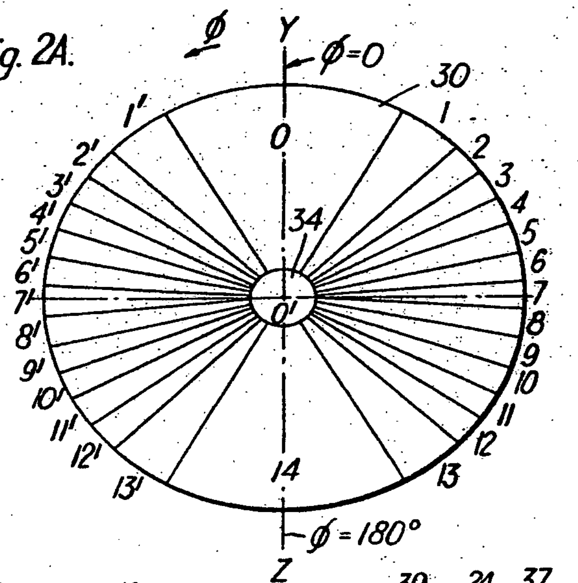
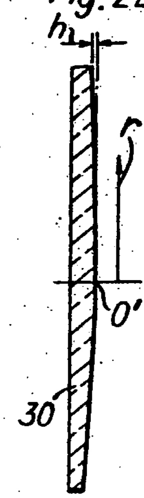


Fig. 2B.



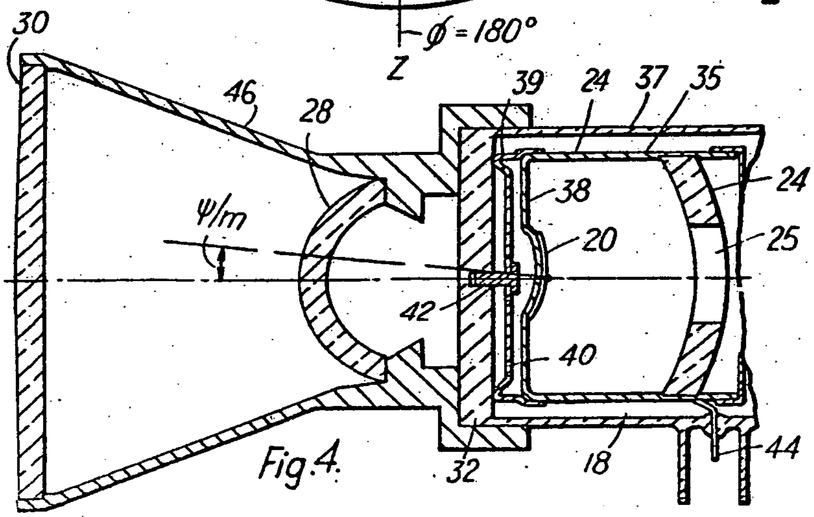


Fig. 4.

897361. COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 2

Fig. 3.

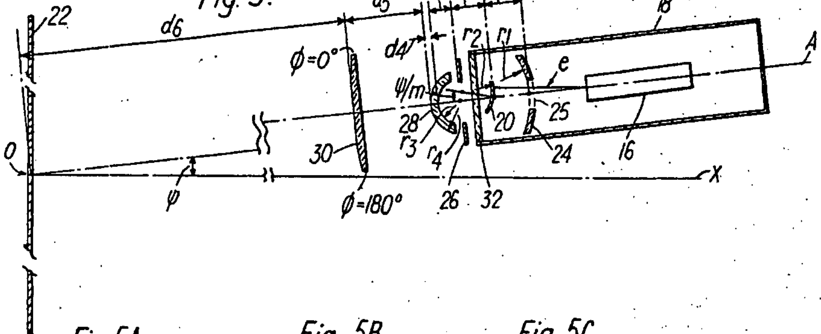


Fig. 6A

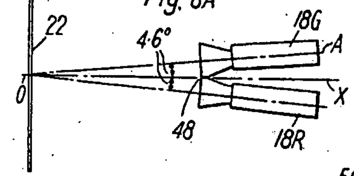


Fig. 6B.

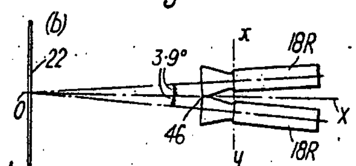


Fig. 6C.

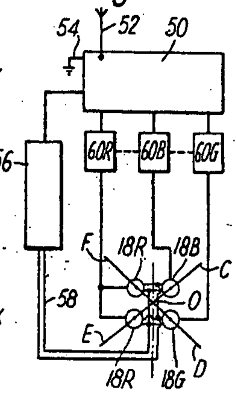


Fig. 7.

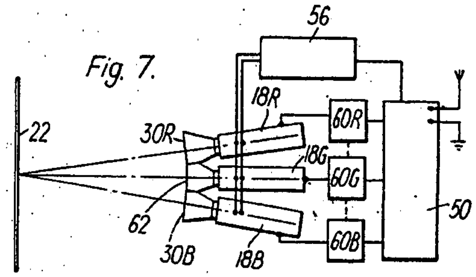


Fig. 5A

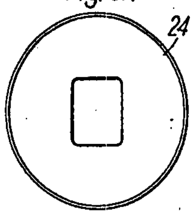


Fig. 5B

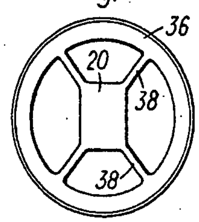


Fig. 5C.

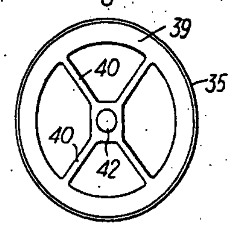


Fig. 8B

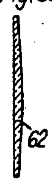


Fig. 8A

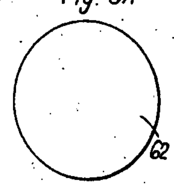


Fig. 9